H2A Scenarios for Delivering Hydrogen from a Central Production Plant to Light Duty Vehicles

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NHA Conference

4/28/04

Renaissance Hollywood Hotel,
Los Angeles CA

H2A Delivery Group Goals

- Develop spreadsheet database on delivery system component costs and performance

- Develop delivery scenarios for set of well defined "base cases" that span major markets and demand levels

- Estimate the cost of H_2 delivery for base cases

Assume 2005 delivery technologies

Delivery Component Workbook

- Allow user to access authoritative information on H_2 delivery component costs and performance in EXCEL workbook format

- "Beta" test version will be released this summer

Delivery Component Spreadsheets

- Each component of H_2 delivery system has separate descriptive EXCEL spreadsheet
- Each component spreadsheet includes
  - ➢ installed capital cost as a function of size,
  - ➢ performance (efficiency),
  - ➢ O&M costs (fuel, electricity, labor, parts, etc.),
  - ➢ equipment lifetime (and economic lifetime, if different);
  - ➢ *for 2005 technology*
- ◆ Spreadsheets also include "generic" or "sample" calculations of how much the component contributes to H_2 delivery costs ($/kg), for parameter ranges of interest

List of Delivery Components

IN DEVELOPMENT

- Compressed Hydrogen Gas Truck (Tube trailer)
- Liquid Hydrogen Truck
- H2 Compression (single-stage)
- H2 Compression (multi-stage)
- Hydrogen pipeline
- Liquefiers
- LH2 Storage Dewars
- Gaseous H2 Storage Cylinders

PLANNED

- Compressed Hydrogen Gas Truck Terminal
- Liquid Hydrogen Truck Terminal
- Gaseous H2 Underground Geological Storage

Microsoft Excel - H2A_StorageDelivery_apr14.xls

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Truck - LH2 Delivery

Calculation Outputs (Be sure ALL data is entered before checking)

Required Revenues ($/year)	$230,899
Delivered Hydrogen Selling Price ($/kg)	$0.444
Real After-Tax IRR (%)	10.0%

COLOR CODING

	= Calculated Cells (do not change formulas)
	= Input Required; Input Used in Revenue Calculation
	= Optional Input; Input NOT Used in Revenue Calculation
	= Information Cells

ERROR: Please check the error messages to the right of the Economic Assumptions table and fix the appropriate row.

Liquid Hydrogen Truck/Tanker Design Inputs

Design Input	Value	Comments	Data Source	Information
Tank Water Volume (m3)	35.0			
Tank Empty Weight (kg)	1.0			
Truck Cab Empty Weight (kg)	15000.0			
Truck Trailer Empty Weight (kg)	25000.0			
Gross Vehicle Weight Limit (kg)	45000.0			
Tank Loading Losses (% of Tank Volume)	3.0%			
Tank Unloading Losses (% of Tank Volume)	7.0%			
Tank Boil-off Rate (% per day)	0.3%			

Liquid Hydrogen Truck/Tanker Delivery Scenario Inputs

Delivery Scenario Input	Value	Comments	Data Source	Information
Tanker Useable Delivery Capacity (%)	95%			
Round-Trip Distance (km)	200.0			
Station Hydrogen Demand (kg/day)	500.0			Please use the pull-down menu to the right of the value

MACRS_Depr. Table | Truck-Tube Trailer Delivery 1 | Truck-Tube Trailer Delivery 2 | Compressed Gas H2 Terminal | **Truck - LH2 Delivery** | L

"Base Case" H$_2$ Delivery Scenarios

Market Type	Early Fleet Market (1%)	General Light Duty Vehicles: Market Penetration		
		Small (10%)	Medium (30%)	Large (70%)
Metro	X	X	X	X
Rural			X	
Interstate			X	

3 Delivery Modes:

Compressed Gas Truck, Liquid H2 Truck; Gas Pipeline

(pure modes; combined modes for each)

Delivery Scenario Workbooks
one workbook per delivery base case
(linked to Delivery Components Workbook)

- Define configuration for each base case and each delivery mode

- Calculate delivered hydrogen cost ($/kg) for each base case and each delivery mode

Define Metro Base Case Configurations

- **2 city sizes (100,000, 1 million)**
  - Ave. population density 700-1200 people/km^2
  - Ave. light duty vehicles/person = 0.5-1.2
- **Central H$_2$ plant sizes 50,000 – 500,000 kg/d**
  - 100 km from city, if city H$_2$ demand << 50 tpd,
  - at city-gate, if city H$_2$ demand $\geq$ 50 tpd
  - H$_2$ storage terminal (assure fuel deliverability): 6 days LH$_2$ or 2 days gaseous H$_2$
- **2 Refueling station sizes 100 kg/d, 1500 kg/d**
  - sited using idealized model of H$_2$ demand density
- **Mass LDV markets**: 0.72 kg H2/veh/day (14,950 miles/yr , fuel econ. 57.5 mpg equivalent)
- **Early fleet vehicles**: 0.96 kg H2/veh/day (20,000 miles/yr , fuel econ. 57.5 mpg equivalent)

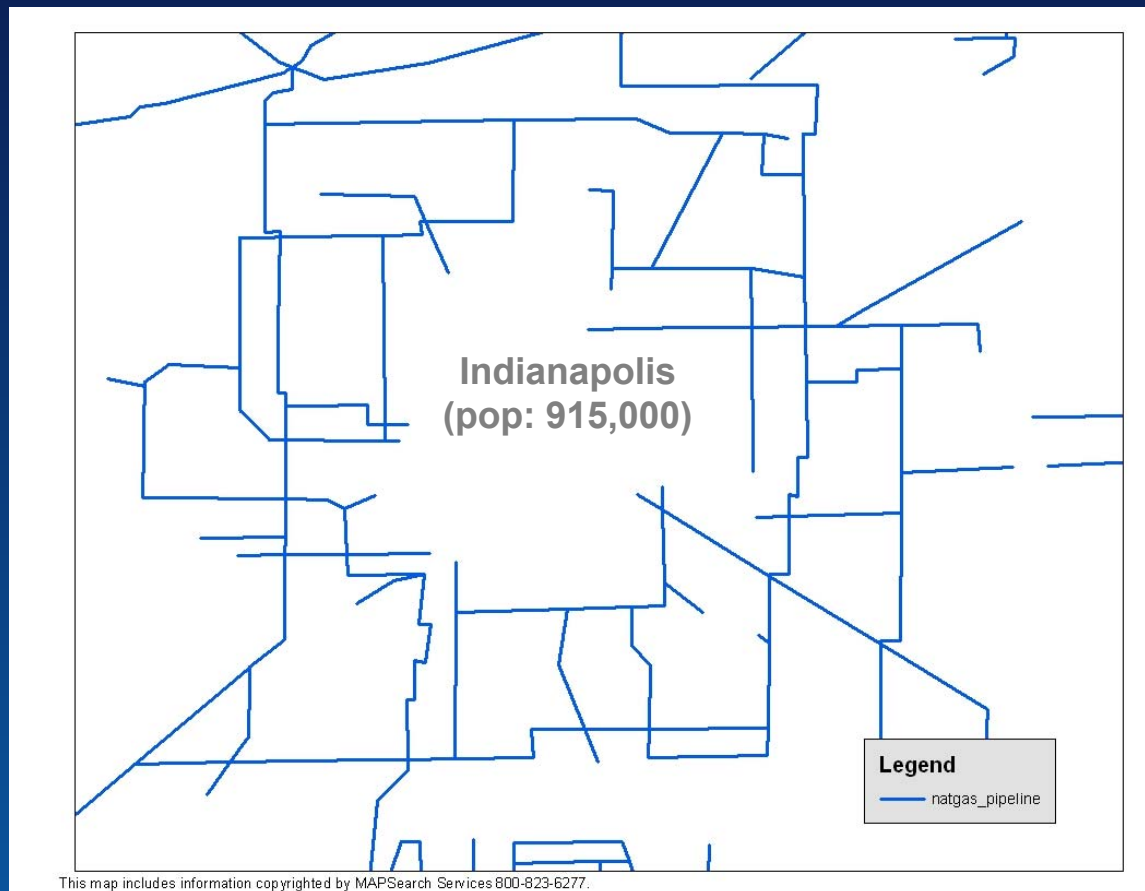# Population Density => Household Vehicle Density => H_2 Demand
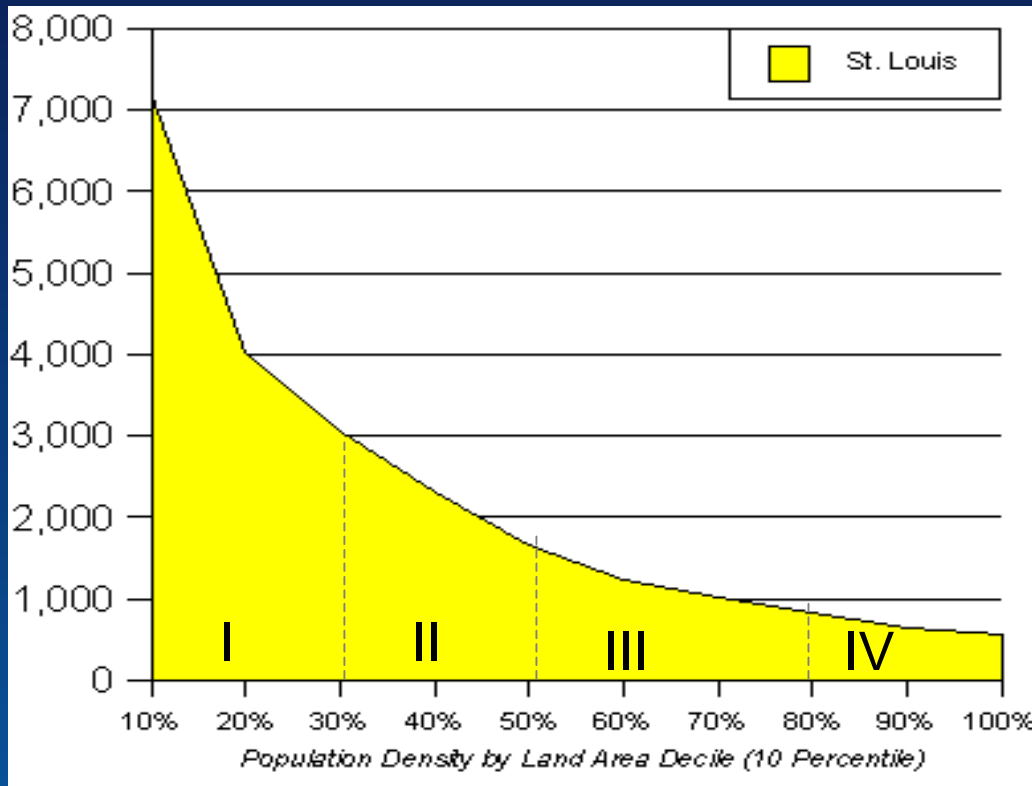
- Population density consistently peaks in 10-20% of urbanized area

- Shape of density function (rate of decline) reflects compactness vs. sprawl

- HH vehicle density rises from <0.5/capita in core to 1.16/capita in outer zones

Generic Large City with 4 Population Density Zones Requires 2 Interconnected Mains
(+ Service Lines)
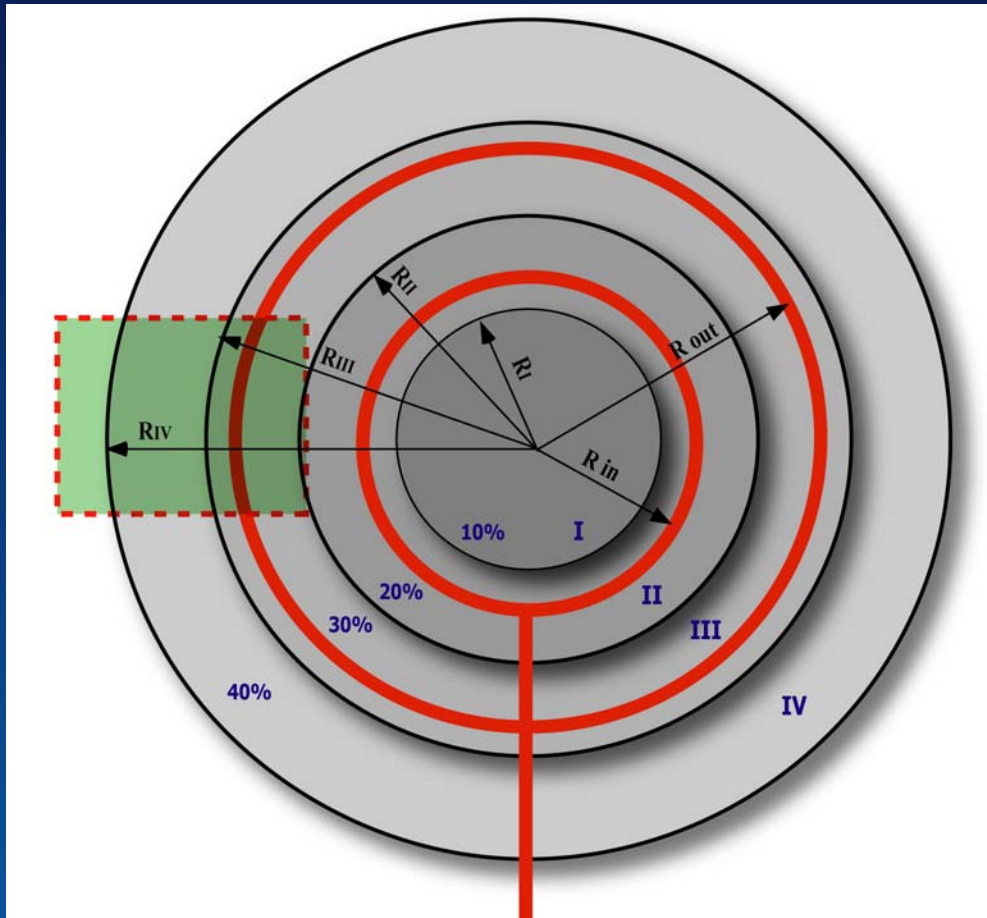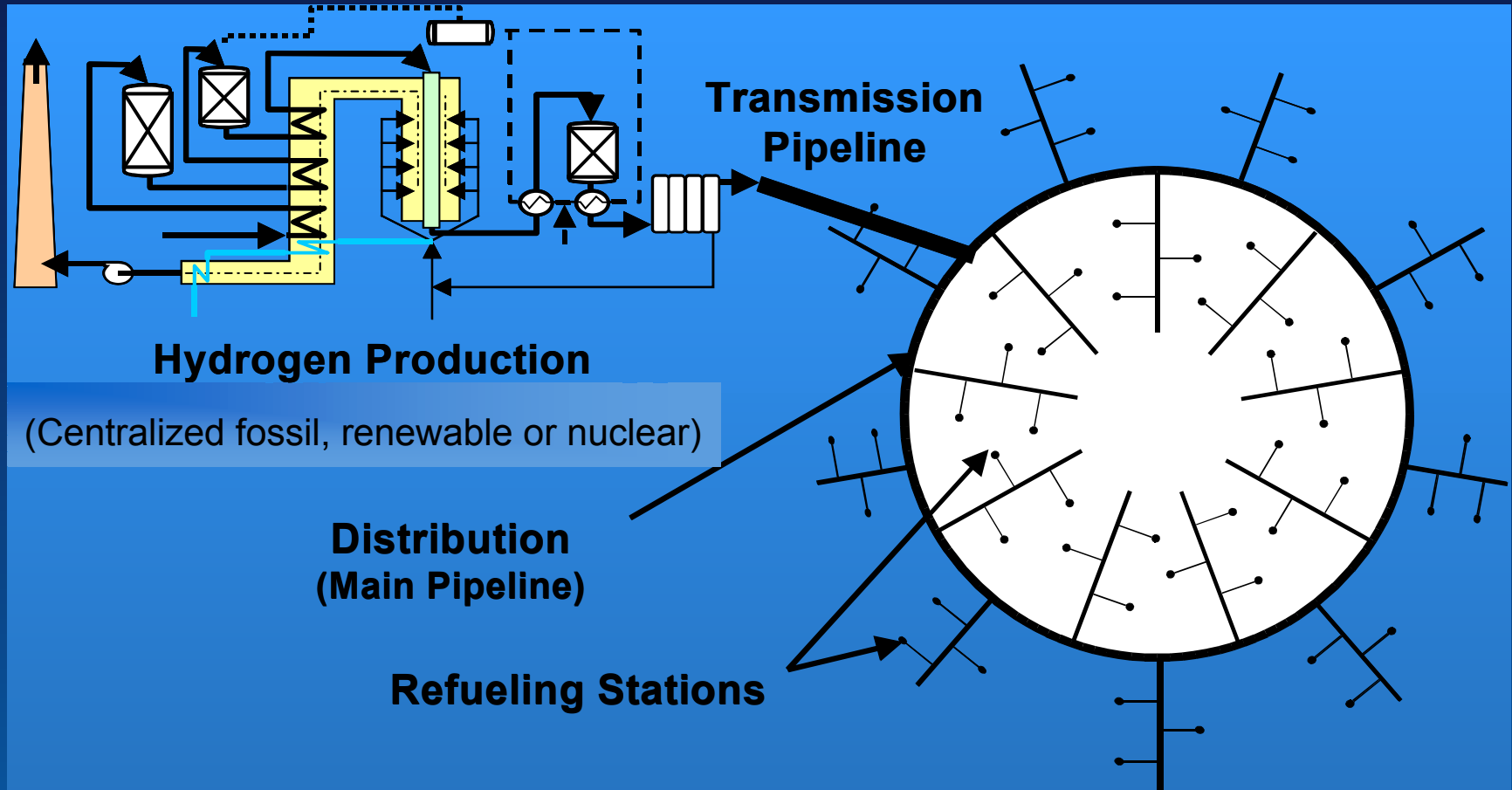

- Diameter of inner and outer mains = function of flow (kg/d) & delivery pressure at forecourt

- Circuity factors correct for noncircular layout

- Pressures:
  800 psi at main inlet
  $\geq$ 200 psi at forecourt

Generic Geometry Compares Well with Observed NG Pipe Geometry for Similar-Sized Urbanized Area

Indianapolis
(pop: 915,000)

Legend
natgas_pipeline

This map includes information copyrighted by MAPSearch Services 800-823-6277.

Generic Small City Requires a Single Distribution Main + Service Lines

Transmission Pipeline

Hydrogen Production

(Centralized fossil, renewable or nuclear)

Distribution (Main Pipeline)

Refueling Stations

Summary: Metro Delivery Scenarios

	Small City				Large City			
	Fleet 1%	10%	30%	70%	Fleet 1%	10%	30%	70%
City H2 Demand tonne/d	**1**	**8.3**	**25**	**58**	**9**	**83**	**250**	**580**
Ave H2 dispensed /sta kg/d	70	1050	1050	1050	70	1050	1050	1050
# H2 Sta.	16	8	24	56	122	61	183	426
H2 plant ->city km	100	100	100	0	100	0	0	0
Ave. # km between H2 sta	3.1	4.4	2.5	1.7	3.2	4.5	2.6	1.7
Comp gas trucks/ trailers	2/20	-	-	-	13/ 150	-	-	-
LH2 Trucks	2	2	5	7	11	7	21	48
Pipeline length km		40	68	121		293	525	980

Interstate Delivery: Rural Interstate DVMT/Mile & mpge=>H2 Demand
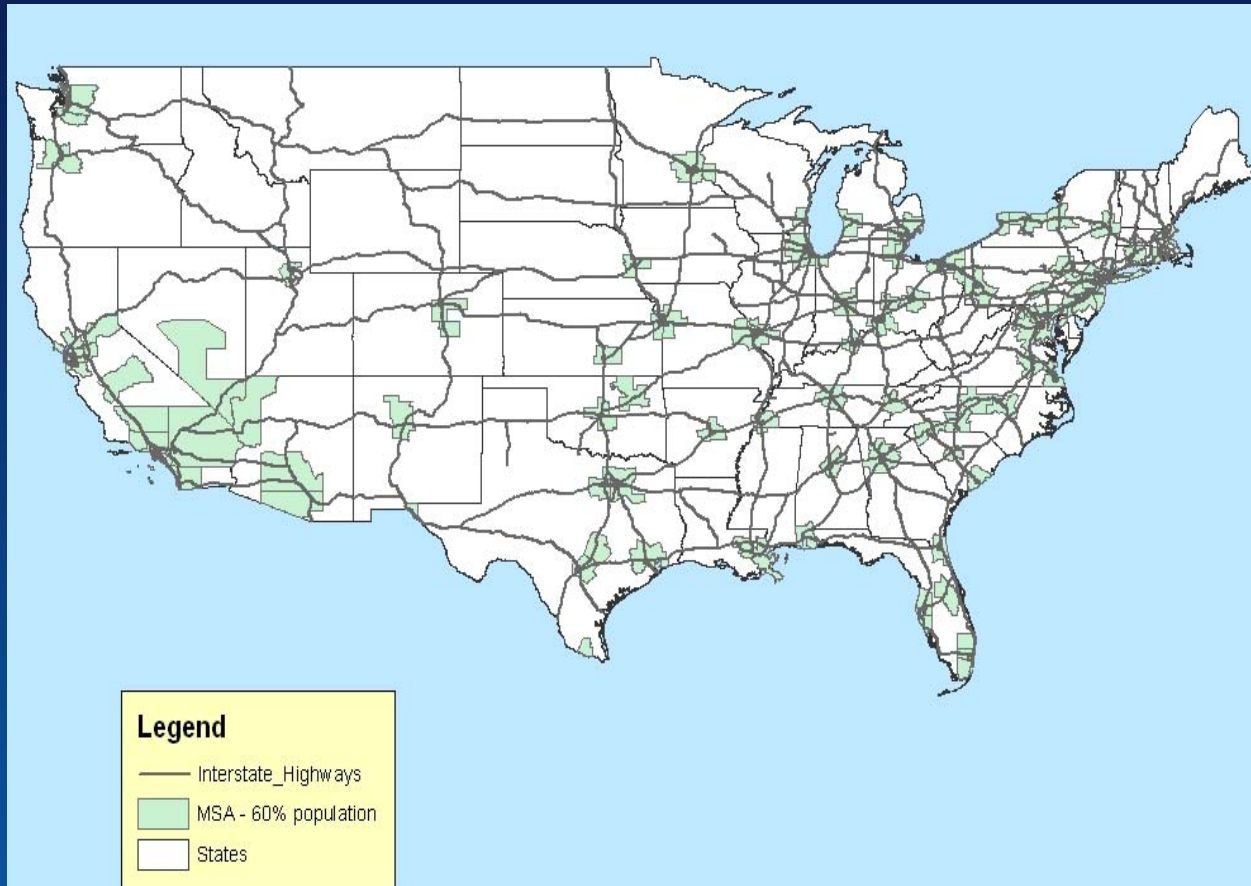
- Today, 10% of light-duty VMT occurs on 33,060 miles of rural interstate highways (FHWA, 2002)

- ~17,000 VMT/d/mi

- At 57.5 mpge, ~400 gge/mi/d needed for peak demand (July weekend day)

Legend
- Interstate_Highways
- MSA - 60% population
- States

Interstate Delivery Scenarios:
160 km segment of rural interstate

	Market penetration: H2 LDVs		
	10%	30%	70%
H2 Demand tonne/d	**3.9**	**11.6**	**27.0**
# H2 Sta. 1500 kg/d	4	12	26
Ave. # km between H2 sta	40	13	6
LH2 Trucks	1	3	5

At 100% market penetration of H2 LDVs, ave. spacing for 1500 kg/d H2 stations ~ today's gasoline stations

Next Steps

- Complete Delivery Component Spreadsheets by End of Summer
- Refine delivery scenarios
  - ➢ Review with industry
  - ➢ Additional scenarios
  - ➢ System design
    production -> delivery -> forecourt
- Compare scenario results
  - ➢ $/kg vs demand
  - ➢ Sensitivity studies
- Complete Delivery Scenario Workbooks by October